times, I felt a positive sadness when I realized that the great visitation was over, and there was silence in the world again, and all were dead that had so recently lived and filled the world with noise and movement. It was almost a painful silence, and I could not but feel that I had lived to witness one of the great events of existence, comparable to the occurrence of a notable eclipse or the visitation of a great comet. Then again the event marked a definite period in my life, and I could not but wonder how changed would be my surroundings, my experiences, my attitude toward life, should I live to see them occur again seventeen years later.

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## THE BEHAVIOR OF FUNDULUS HETEROCLITUS ON THE SALT MARSHES OF NEW JERSEY

DURING the year 1914–'15 the writer was retained as consulting zoologist to the department of entomology of the New Jersey Agricultural Experiment Station and engaged in studying the fish enemies of the salt marsh mosquitoes. At that time it became evident that *Fundulus heteroclitus* is the most important predatory fish attacking the salt marsh mosquitoes of northern waters. Much evidence of the efficiency of *Fundulus heteroclitus* as a mosquito exterminator has already been published (Chidester, 1916). Certain notes on its behavior under varied conditions have been amplified by more recent observations and are herewith presented in connection with the problem of migration in fishes.

In New Jersey the fish were studied under natural conditions for over a year on the salt marshes near the city of New Brunswick. Through the report system of the state inspectors of the Mosquito Commission, much important information was secured regarding conditions in other parts of the state. Experimental conditions were induced in the field by drainage ditches and in the laboratory by the use of aquaria. Other studies were made at Woods Hole, Mass., for several years during a portion of the month of June.

### MATERIAL AND METHODS

On the salt marshes where the chief study was made there were numerous pools, some permanent, others easily differenti-

ated as temporary. The bottoms of the permanent pools were covered with soft mud and strewn with sedge and eel grass frequently dispersed in windrows as a result of repeated wave action. The bottoms of the temporary pools were covered with matted grass bound together by hardened clay.

At the Bonhamtown marshes near New Brunswick, intensive study was made of three large permanent pools, one of which was partially drained by a ditch connecting it with the Raritan River. Additional studies were made of conditions in many other permanent pools, temporary pools and ditches.

The three permanent pools studied most intensively were quite different in their character. The largest one was about 40 feet long and ranged from a foot to 10 feet in width, but its depth varied considerably with the tides. At its larger end it was connected with the Raritan River by means of a long narrow drainage ditch. The second was an almost circular pool about 25 feet in diameter and in no place more than 18 inches deep; much of the time it was only about 6 inches deep. The third pool was about 30 feet long and about 10 feet wide. At one end it was 20 inches in depth and at the other about 12 inches.

Collections were made by means of a 20-foot minnow seine and several small dip nets. Fish were frequently preserved in weak formalin in the field when it was desired to examine their stomachs at leisure. Usually, however, they were brought to the laboratory and examined freshly killed or else liberated in aquaria.

Records of temperature, salinity and specific gravity were taken with each collection, while the height of the tidal flow and the depth of the pools were approximately recorded.

## SPRING MIGRATION

In the early spring, usually during the latter part of March, *Fundulus heteroclitus* begins its migration from the mouth of the Raritan River up beyond the salt water to the slightly brackish water of the salt marshes and even into fresh water creeks.

At first large numbers of medium-sized males appear, followed soon after by the medium-sized females (three or four years old) and later by the large and small of both sexes. By the middle of April great shoals of small fish crowd the streams and penetrate to the shallows. They seem undeterred by the sewage pollu-

tion of the river and are apparently impelled to seek out the farthest limits of tidal water.

Spawning takes place in April and continues until July in the region studied.

The factors influencing inland migration in the spring are several. The *temperature* of the inland waters which is at that time slightly higher than that of the ocean, and will later continue to increase, undoubtedly plays an important part. The fresh water teeming with life and the salt marshes with myriads of insect larvæ, shrimps, and young fish furnish *food* for the vigorous hungry fishes. The currents of fresh water have become stronger and as the fish needs must react to a stream of water not absolutely toxic to it, there is thus a *pressure stimulus* which powerfully attracts. Of perhaps less importance is the fact that the fresher waters when not too greatly contaminated by sewage pollution are *richer in oxygen*. Certain it is that many fish not anadromous come near the shore to spawn. Possibly the greater metabolism incident to the development of eggs and sperm causes them to seek out water which has a higher oxygen content. Roule (1914) believes that salmon migrate to a richer supply of oxygen. Wells (1915) has shown that starvation may cause certain fishes to seek water of lower concentration of salts and other species to behave in the opposite manner.

## Summer Habits

During the summer until early August there is continual migration inland with the tides, many of the fish returning to the brackish water of rivers and creeks as the tide ebbs from the marshes. Some few individuals of the species *Fundulus heteroclitus* find sanctuary in the marsh pools, and in all probability so habituate themselves that they remain until cold weather. From the three permanent pools not partially drained by ditches, collections made during the year furnished the following species.

| Number of Collections | Fundulus het. | Cyprinodon var. | Apeltes quad. | Anguilla |
|---|---|---|---|---|
| 29 | 1,581 | 105 | 19 | 22 |

Since *Fundulus majalis* did not appear on the Bonhamtown marshes it was not feasible to repeat with that species the observations of Mast (1915), who found that it is not only prone to move with the tides, but that if the outlet to the ocean is plugged,

the fish will convey themselves overland by flopping in the general direction of the ocean. Mast shows that the fish are able to keep their sense of direction in the overland course and concludes that they remember the outlet. He believes that since there are apparently no external factors capable of guiding them, the behavior is dependent on internal factors.

*Fundulus heteroclitus* does not as a rule leap from pools, when left by the gradually receding tides. Two permanent pools were available for the study of the reactions of this species, one of them being connected with the Raritan River by a drainage ditch during the course of the study. This pool had been under continuous observation in an undrained condition and through an error workmen ran a drainage ditch to it, which did not, however, completely remove the water. After two days of the resultant condition the ditch was plugged with heavy sods and observations continued as before. The day after the ditch was plugged it was noted that there were many *F. heteroclitus* scattered all around the margin of the large oval pool. Although it was $25 \times 15$ ft., there was no marked variation in the distribution of the dead fish, except that there were none at the end farthest from the outlet. The banks were gently sloping and afforded an easy egress in any direction. The second pool with an outlet was long and narrow with high banks and was partially drained at the ebbing of the tide. When the receding water had left certain of the fish near the shallows at the exit, there was the usual attempt of the majority of fish to follow an outflowing current. But few individuals were caught in the mud, the majority returning to the deeper pool.

Since there is one predominant reaction in fishes, that to currents, it is quite probable that with *Fundulus heteroclitus* there is a less marked reaction to ebb tide. In the case of *Fundulus majalis* under natural conditions there must be an extremely rapid reaction to the condition of slack tide. Their disturbance under experimental conditions induced by Mast (1915), who plugged the entrance of the tide as it was coming in, indicates that this species does not normally accommodate itself to still water and that its stay inland is determined only by the tidal rise.

In the case of *Fundulus heteroclitus,* which migrates inland to the extremely shallow water covering the salt marshes at high tide, there is no such immediate response to receding water. The

fish return less quickly and seem to become readily acclimated to the still waters of permanent or even temporary pools to which they are directed as the tides recede.

In August there is a period of over two weeks when actively feeding killifish are almost completely absent from the marshes. That temperature plays a most important part in this behavior is indubitable. Shelford and Powers have shown (1915) that the herring is sensitive to temperature differences as small as 0.2° C. They have demonstrated that alkalinity and acidity are more important than salinity. The herring and salmon experimented with reacted to small fractions of a cubic centimeter per liter of $H_2S$ and became negative to sea water which was slightly more acid than the fresh. It is possible that increased temperature may bring into solution organic substances which alter the alkalinity of the sea water or even render it acid near sources of pollution. Johnstone has shown (1908) that the migration of herring in Europe is closely associated with the salinity and temperature of the sea.

We may safely assume that *Fundulus heteroclitus* has an optimum temperature for its metabolism which will be higher when the animal is weak and poorly nourished, but lower when it is well fed. Thus a gradually increasing temperature while the animal is feeding will finally result in such warmth that normal metabolism is no longer possible and there will be no return to the fresher waters until they become cooler. Another factor of great importance in the inland movements of *Fundulus* is the fact that after spawning, the animals are sluggish and hence in no condition for a battle with the tides. This factor is probably the one that causes almost complete disappearance of the larger and the medium-sized *Fundulus* during August in the area studied.

### Fall Migration

Early in September large numbers of *Fundulus heteroclitus* of small and medium size return to the marshes with the tides, and they continue to run in and out until the water becomes extremely cold. There are fewer individuals remaining in the pools between tides, but many are still found variously dispersed among temporary pools far inland.

Their food is somewhat reduced so far as mosquito larvæ are concerned, but there are many other insects available, besides small eggs and shrimps.

## WINTER HABITS

The habits of *Fundulus heteroclitus* in the ocean in winter are not fully known. The late Vinal Edwards of the U. S. Bureau of Fisheries, Woods Hole, Mass., stated to the writer that it was his observation that they spend a large part of the winter near the mouths of rivers in water which is moving and which is at a salinity slightly lower than that of the sea.

In November, when the temperature of the water on the marshes goes down to 40° F., the migration inland is much reduced. Field observations showed that fish in temporary pools at this time attempted to burrow in the bottoms and being of course unsuccessful on account of the hardness of the clay died during the night as the temperature went down to nearly the freezing point. In the case of permanent pools whose bottoms were covered with soft mud, the fish burrowed down during the night and emerged when the sun came out and warmed the water.

At about the time that ice begins to form over the permanent pools, migration ceases so far as the marshes are concerned. In the pools, fish were found burrowed in the mud at a depth of from 6 to 8 inches in the middle of the winter. The temperature of the mud was from 40° F. to 45° F. and that of the water ranged from 32° F. to above 40° F., even in February, since the shallower pools were warmed considerably by the sun. On bright days when the sun was most effective, a few hardy fish ventured forth from hibernation and swam slowly around under the ice, feeding but little. Associated with them were shrimps, myriapods, eels and another minnow (*Cyprinodon* var.), all of which were burrowed in the mud during most of the winter.

Examinations of the stomach contents of *Fundulus* showed that the food during the winter was largely algal matter in those individuals that became active. By far the majority of the fish remained torpid until early spring, beginning to feed again in March, and reassuming complete activity early in April.

## SUMMARY

1. Field studies of *Fundulus heteroclitus* were made throughout one entire year on the salt marshes of New Jersey.

2. Spring migration begins in March and is probably caused by several factors, including the higher temperature of the inland water; currents due to high tides and rainfall; the need

for food available in fresh water; greater metabolic activity due to gonad development which demands a greater oxygen supply.

3. Summer activities consist in spawning, feeding, lazy movements from the marshes to the brackish water and back again.

4. In the autumn, migration is less constant and the larger fish are less numerous.

5. In the winter, migration ceases entirely as the marsh pools are scumming with ice. Some landlocked individuals burrow into the mud of permanent pools, coming out occasionally as the sun warms the water. Many fish are killed by the cold as they remain in temporary pools with bottoms composed of caked mud and grass offering no shelter.

6. The majority of *Fundulus heteroclitus* return to salt water in the winter, probably remaining near the mouths of rivers until spring.

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BIBLIOGRAPHY

Chidester, F. E.
1916. A Biological Study of the More Important of the Fish Enemies of the Salt Marsh Mosquitoes. Bull. 300, N. J. Ag. Exp. Sta., pp. 1–16.

Johnstone, J.
1908. Conditions of Life in the Sea. 332 p. Cambridge.

Mast, S. O.
1915. The Behavior of *Fundulus* with Especial Reference to Overland Escape from Tide-pools and Locomotion on Land. *Jour. An. Beh.*, Vol. 5, pp. 341–350.

Meek, A.
1916. The Migrations of Fish. 427 p. London.

Shelford, V. E., and Allee, W. C.
1914. Rapid Modification of the Behavior of Fishes in Contact with Modified Water. *Jour. An. Beh.*, Vol. 4, pp. 1–30.

Shelford, V. E., and Powers, E. B.
1915. An Experimental Study of the Movements of Herring and Other Marine Fishes. *Biol. Bull.*, Vol. 28, pp. 315–334.

Wells, M. M.
1914. The Reaction and Resistance of Fishes to Temperature. *Trans. Ill. Acad. Sci.*, Vol. 7.
1915. The Reaction and Resistance of Fishes in their Natural Environment to Salts. *Jour. Exp. Zool.*, Vol. 10, pp. 243–283.
1915. Reaction and Resistance of Fishes in their Natural Environments to Acidity, Alkalinity and Neutrality. *Biol. Bull.*, Vol. 29, pp. 221–257.